BNL - FNAL - LBNL - SLAC

LARP BEAM INSTRUMENTATION and RF

A. Ratti

LBNL

Presented at the DoE review of LARP

Fermilab

July 13-14, 2009

LARP

Outline

Overview of Beam Instrumentation Program

Summary of instruments contributed to LHC
- Schottky Monitor (lead by FNAL)
- Tune Feedback (lead by BNL)
- Luminosity Monitor (lead by LBNL)
- AC Dipole (lead by UT first, now BNL)

Highlights of FY09 activities
- Lumi Monitors
- AC Dipole
- LLRF Modeling
- Synch Light Monitors – New Activity

Integration and commissioning at CERN

Instrumentation Highligths

Instrumentation has contributed components that will enhance the LHC commissioning and operations

Major contributions to the LHC and US colliders

- Tune and Coupling feedback is a world first, accomplished in RHIC
- The AC dipole concept came from LARPs collaborations

  now installed in all three hadron colliders
- The LHC Schottky monitor lead to the upgrade of the Tevatron system
- The luminosity Monitor is designed to survive a level of radiation 100x larger than ever seen before
- LLRF modeling expands the available tools from PEP-II operations
- Adding synch light monitoring on proton storage ring – world first

Graduate students and postdocs involved in most areas

AC dipole, LLRF, Lumi

LARP's Instruments in LHC Commissioning

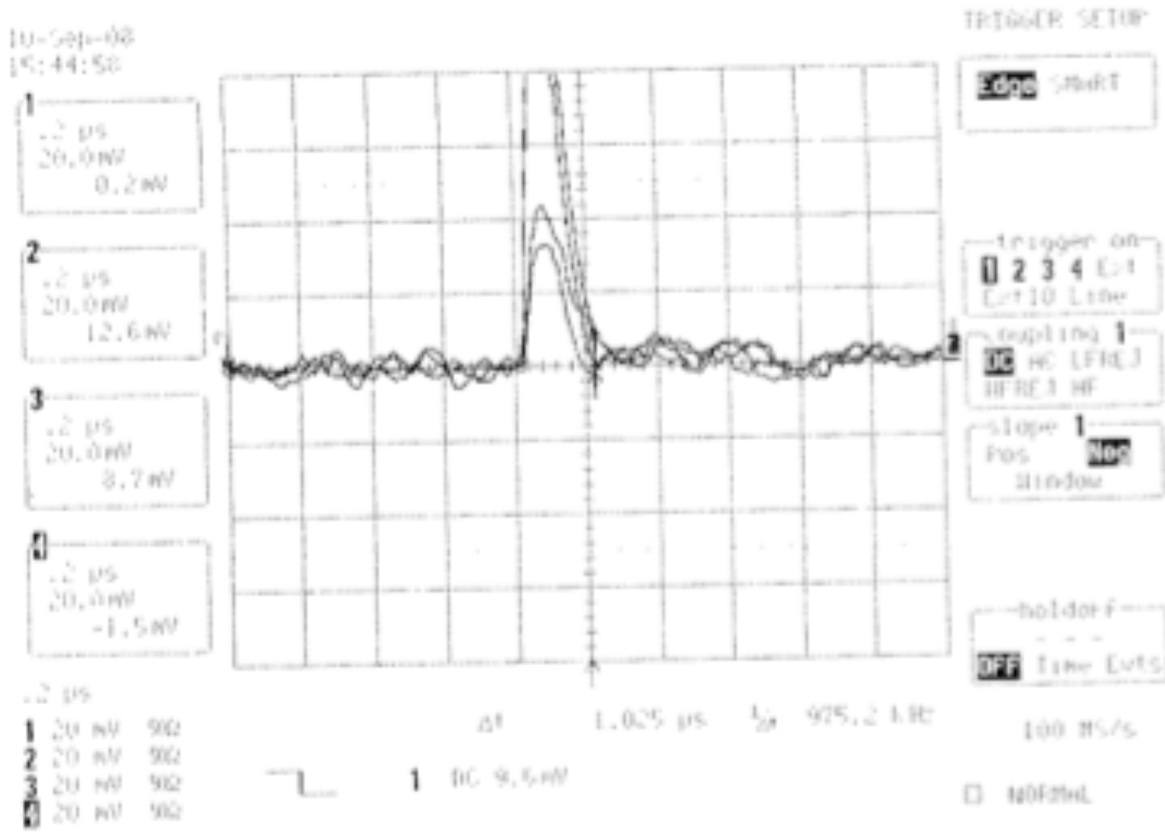
LARP instruments are installed and ready for beam commissioning

- Luminosity monitors – beam signals on day 1
- Tune and coupling – enough to publish LHC-Performance-Note-007
- LLRF modeling – LARP contributed to system tuning before beam commissioning
- Schottky monitors
- AC Dipole

New in FY09 – Synchrotron Light monitoring system – abort gap monitor

- New capability made possible by LARP's contribution
- Built by CERN
- Expected to be ready for 2009 run

LHC - Sep 10, 2008



Beam Signals on Lumi Monitor

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Collaborative Efforts

LARP Instrumentation works with CERN in different ways

1. LARP and CERN equally involved in the developments and implementation
    - AC Dipole – each lab built a system for own collider
    - Tune and Coupling Feedback – System developed and tested in RHIC, CERN implemented in LHC

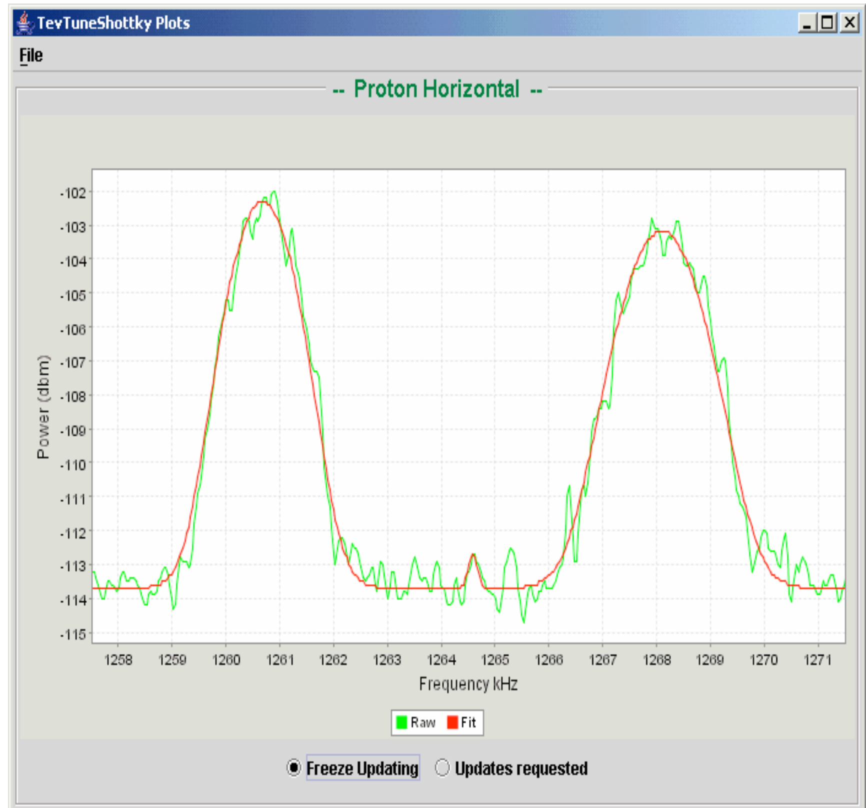
2. LARP did studies and provided prints, CERN implemented in LHC
    - Schottky Monitor – FNAL built processing electronics modeled after the tevatron's
    - Synch Light Monitor – study by LARP, fabrication and installation by CERN

3. LARP did most of the work, CERN provided local support only
    - Luminosity Monitors

Schottky Monitors

Advanced enabling technology for:

- Non invasive tune measurement for each ring from peak positions
- Non invasive chromaticity measurements from differential width
- Measure momentum spread from average width
- Continuous online emittance monitor from average band power
- Measure beam-beam tune shift



Build in capability to monitor gain variation with time

Measure individual or multiple bunches

Technical Approach

Center frequency of 4.8 GHz

3dB BW - 300 MHz

Sufficient for 25ns bunch spacing

Small longitudinal Z/n

No absorbers allowed

Below frequency of Schottky band overlap

Allows for adequate physical aperture

Matched pairs of SiO_2 Coax cables

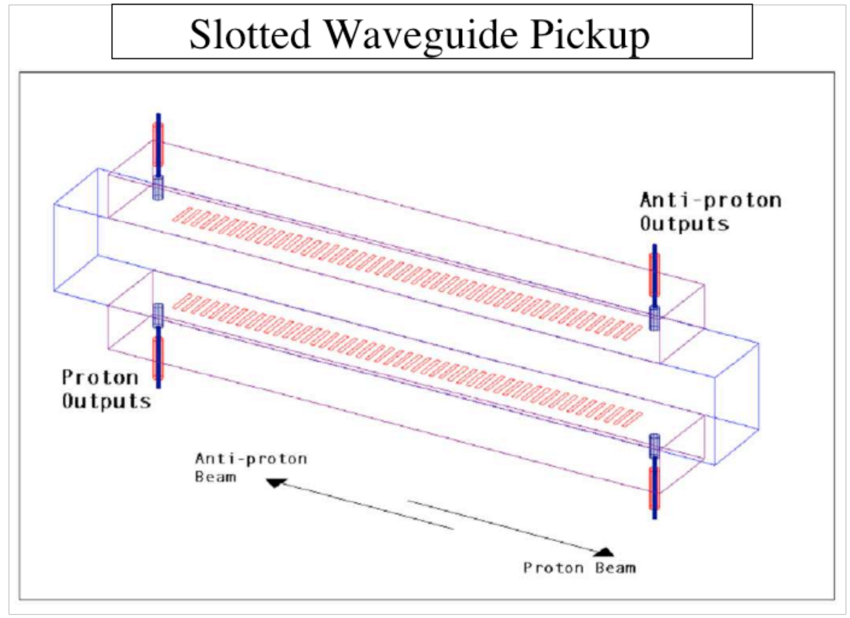
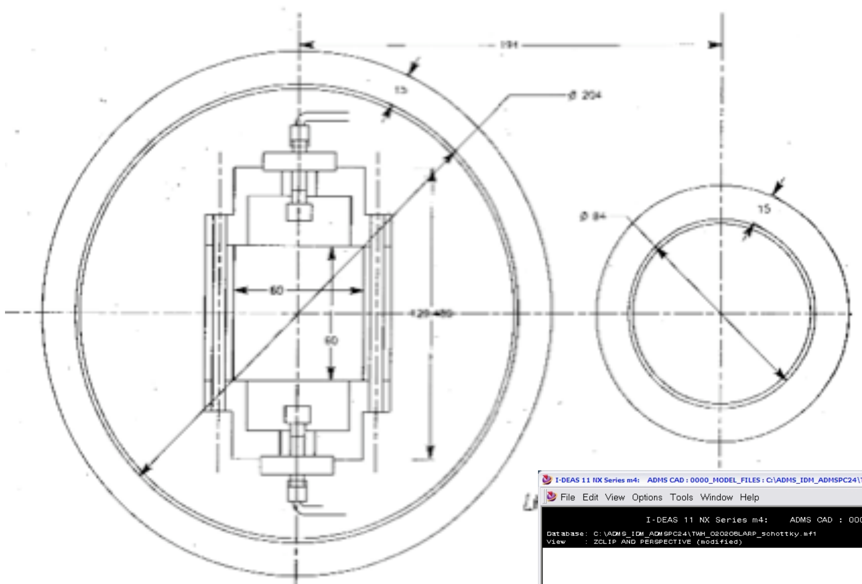
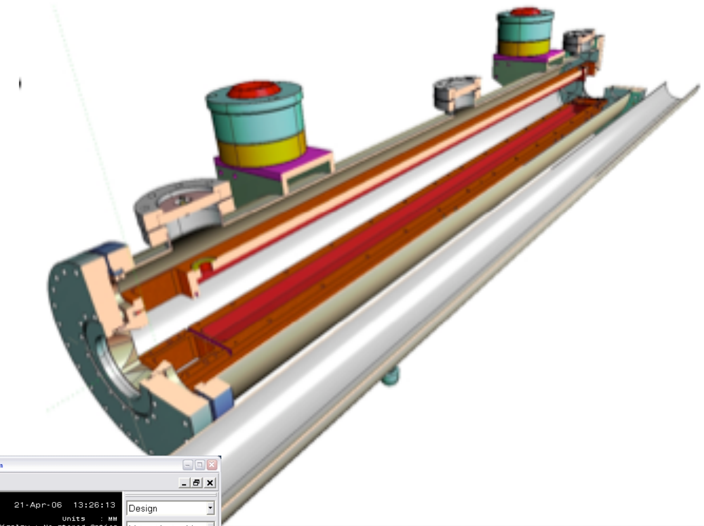


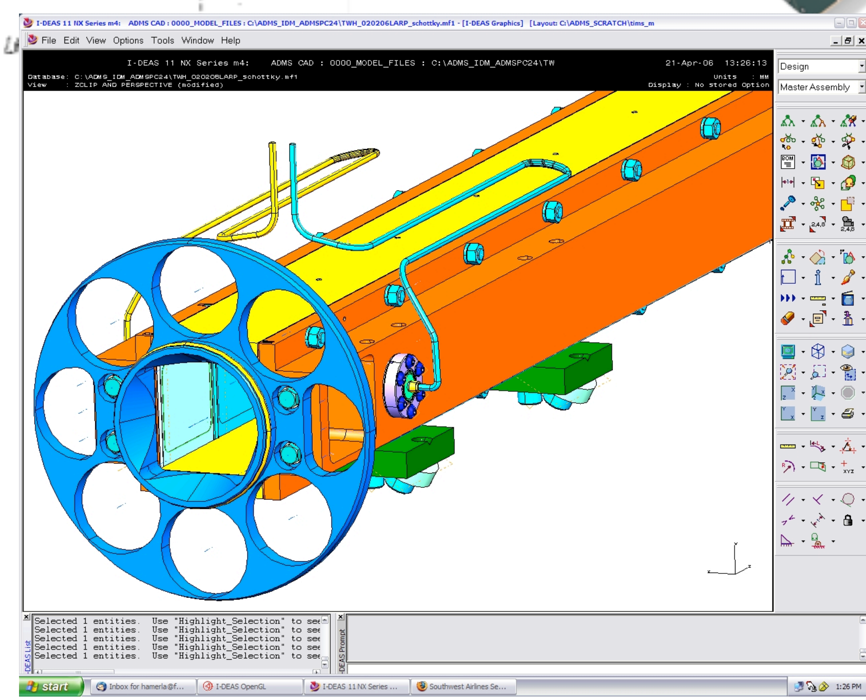
Table 1. Parameters of LHC Schottky Pickup (unit: mm)

Slot length	Slot width	Slot Spacing	Number of Slots	Waveguide width	Waveguide height	Beam pipe width	Beam pipe height
20.52	2.032	2.032	246	47.549	22.149	60.00	60.00

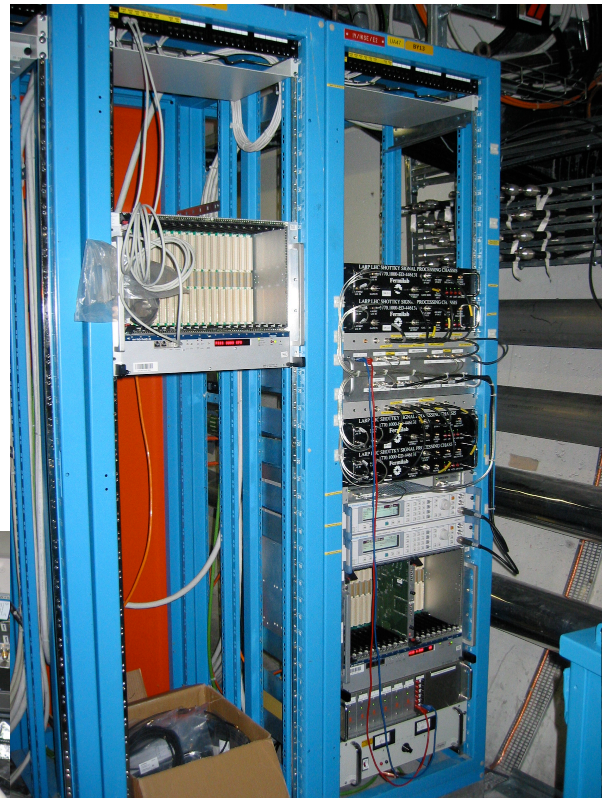
Pickup and Adjacent Beampipe Designed at FNAL

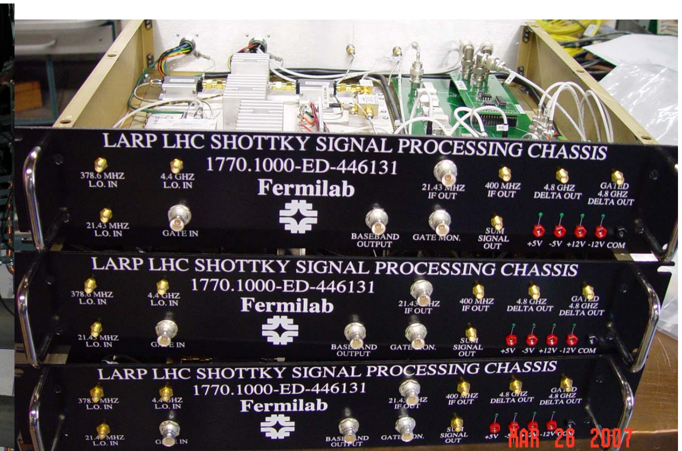


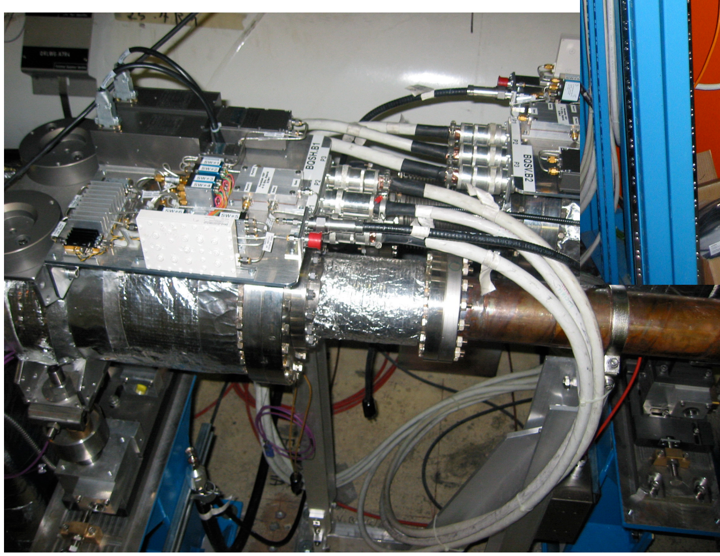




Electronics Hardware at CERN







Tune and Coupling Feedback

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Objective: Control Tune and Coupling feedback

- Develop chromaticity tracking during ramp and store

Acomplishments

- Simultaneous Tune and Coupling feedback used in RHIC run 6, **a world first**
- RHIC run 7 and 8 - Tune and Coupling feedback operational
  - focusing on chromaticity tracking

Task ended in FY07

Moved on to chromaticity control studies

Direct Diode Detection system is an excellent tool for Beam Transfer Function Measurements

Chromaticity Tracking and Feedback

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Challenge:

- persistent current effects in SC magnets can strongly perturb machine lattice, especially during energy ramp (aka "snapback")
  - Betatron tunes ($Q_{x,y}$) and chromaticities ($Q'_{x,y}=EdQ_{x,y}/dE$) can vary significantly due to "snapback" resulting in beam loss, emittance growth.
- Effects for LHC predicted to be large.

Solution: make fast, precision Q, Q' measurements and use these signals to feedback to tuning quadrupoles and sextupoles.

This effort is ideally suited for a collaboration with RHIC, which can be the benchmark and testing ground for this effort.

- slow (1Hz) radial (1mm) modulation – next slide
- faster phase modulation – under investigation

AC Dipole

LARP

Started in FY07, lead by S. Kopp (UT, Austin)

FNAL graduate student PhD project

now Toohig fellow

VERY active involvement from BNL, FNAL and CERN

All three labs are implementing or planning for AC dipole activities

All labs contributing resources to make it happen

LARP committed to develop concepts on US colliders and provide system description for CERN to implement in LHC

AC dipole for the LHC

Most useful @ commissioning
- Measurements are FAST!

Linear optics measurement
- Measure β function and phase advance
- Measure β function at IP
- Linear coupling measurement

Local coupling measurement

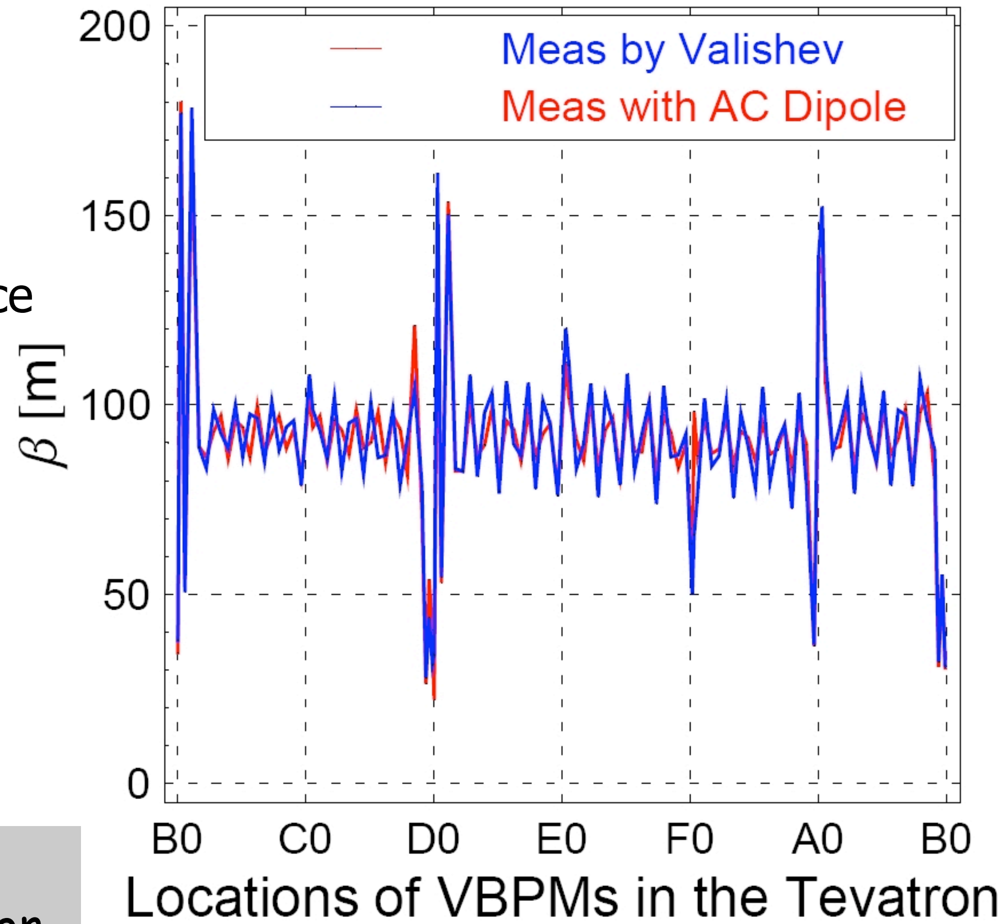
Non-linear driving term measurement

Dynamic aperture measurement

Must be

Long lasting large coherent oscillation with ε preserved

FNAL TeV @ 150 GeV



Parameters of RHIC, TeV, and LHC

Machine	RHIC	Tevatron	LHC
E [GeV]	250	980	7000
f_{rev} [kHz]	78	48	11
γ, 1- γ	0.69, 0.31	0.58, 0.42	0.3, 0.7
f_d [kHz]	55	20.5	3, 8,…
δ	≥ 0.01	≥ 0.01	≥ 0.01
β_{arc} , β_{d} [m]	45, 11	80, 47	180, 260
σ [mm]	0.75	0.5	0.3
$\beta_d l$ [Gm] (4 σ)	140	140	165

FY09 Actvities

Demonstrate the technique of linear gradient error correction based on the optics measurement using AC dipole at RHIC

G. Wang, M. Bai(100% BNL contribution)

Demonstrate Dynamic tuning technique with RHIC high Q ac dipole

P. Oddo (100% BNL contribution)

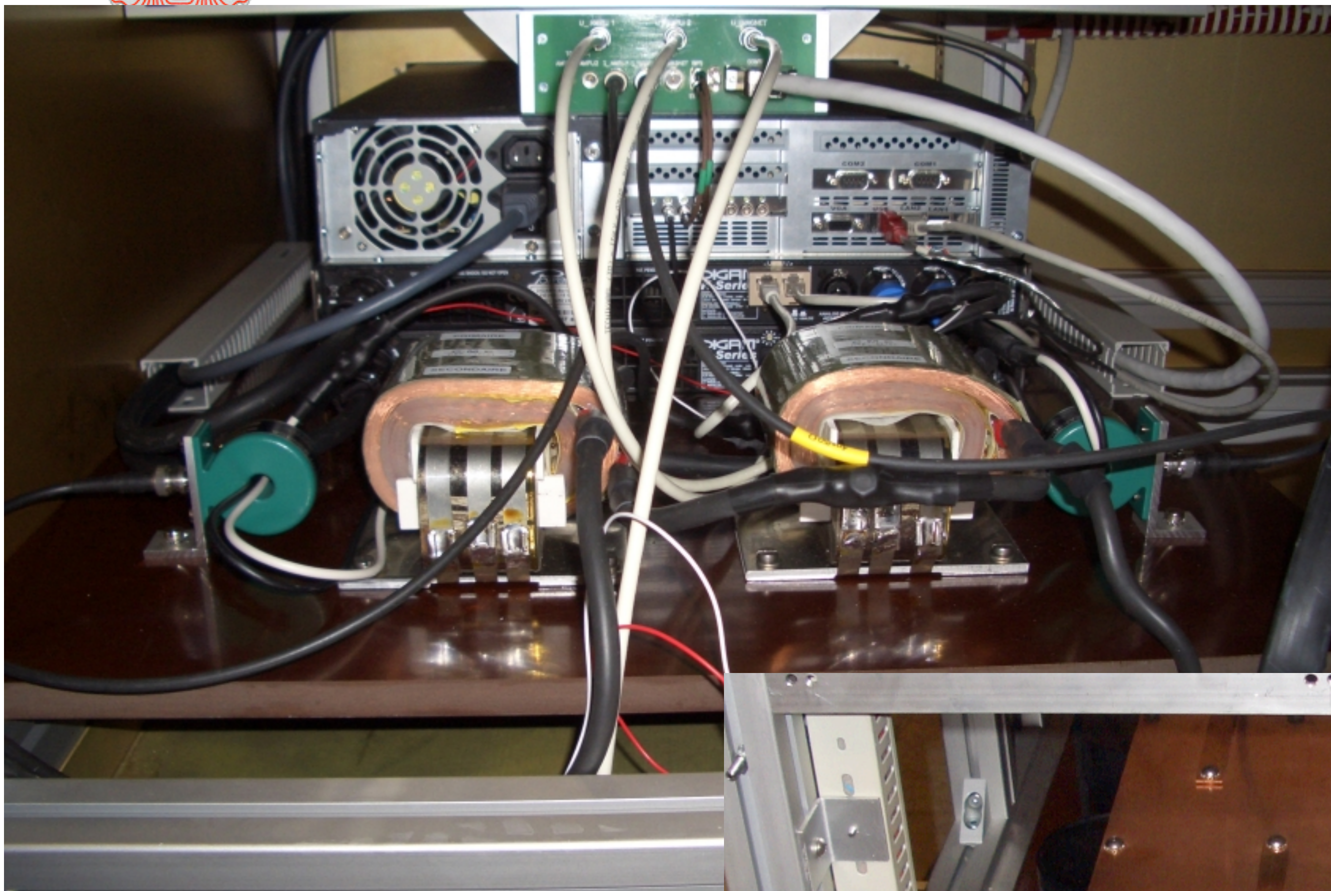
LHC Specs

Frequency: 2750 Hz - 4000 Hz

Amplitude: 1700 A peak (4σ)

Ramping: 200 ms ramp up, 200 ms flat top, 200 ms ramp down

4 AC dipoles have been installed in LHC



2 magnetically coupled audio amplifiers

“Capacitor Bank” for frequency tuning.

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LUMI - Requirements

Requirements (Lumi mini Workshop, 16-17 Apr. 99)

- Absolute L measurement with $\delta L/L \sim 5\%$ for $L > 10^{30}\ cm^{-2}sec^{-1}$
- Cross calibration with LHC experiment measurements of L (every few months)
- Sensitivity of L measurement to variations of IP position ($x^*, y^* < 1mm$) and crossing angle ($x^{*\prime}, y^{*\prime} < 10\mu rad$) less than 1%
- Dynamic range with "reasonable" acquisition times for 1% precision to cover $10^{28} cm^{-2}\ sec^{-1}$ to $10^{34} cm^{-2}\ sec^{-1}$
- Capable of use to keep machine tuned within ~ 2% of optimum L
- Bandwidth 40 MHz to resolve the luminosity of individual bunches
- Backgrounds less than 10% of the L signal and correctable

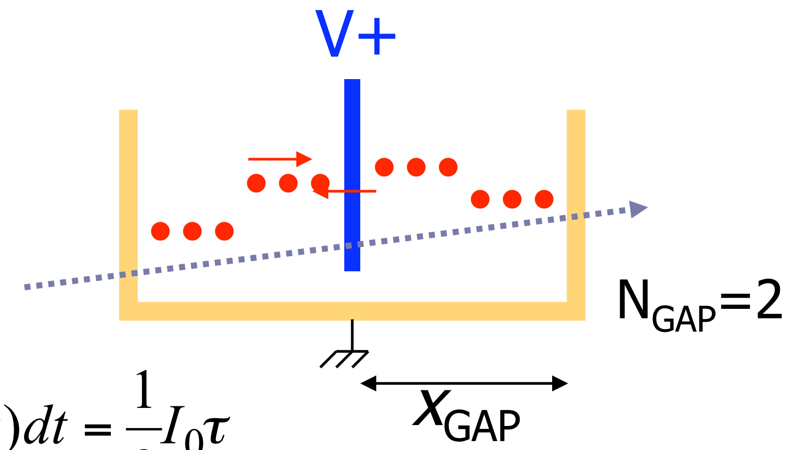
LBNL
25 Jan. 2002

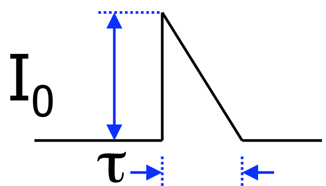
40 MHz Ionization Chamber
W.C. Turner

11

Necessary to optimize beam collisions at high luminosity IPs

LUMI - Conceptual Design
Argon Ionization Chamber





$$\tau = x_{GAP}/v_D \quad Q = \int_0^{\tau} I(t)dt = \frac{1}{2} I_0 \tau$$

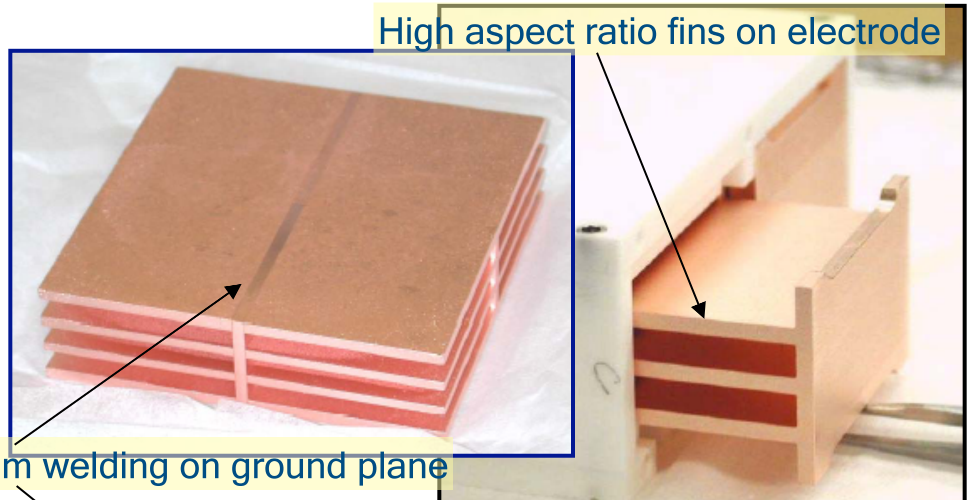
Signal is proportional to the number of parallel gaps
Capacitance add up with n. of gaps + slows down the signal

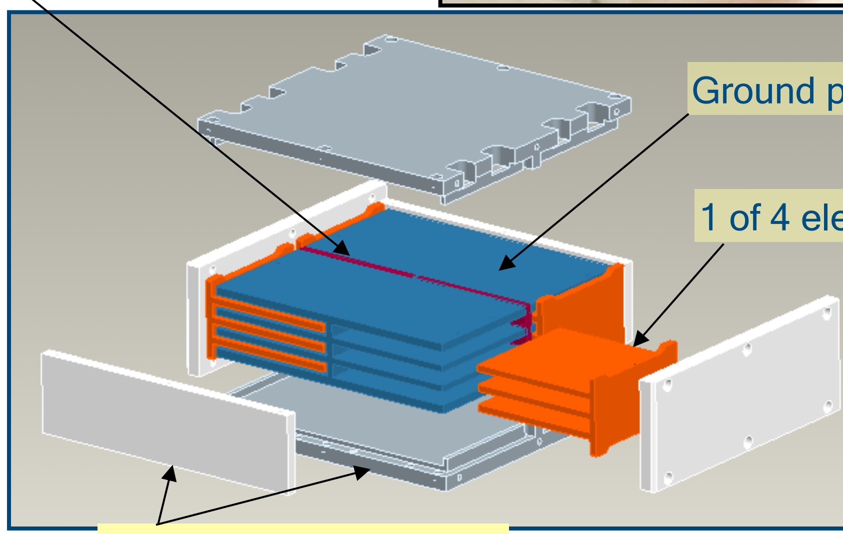
→Optimized for 6 gaps
→Must live in a radiation environment 100x worse than accelerator instruments have ever seen

- →~10GGy/yr, ~10^{18} N/cm^2 over lifetime (20 yrs), ~10^{16} p/cm^2 over lifetime

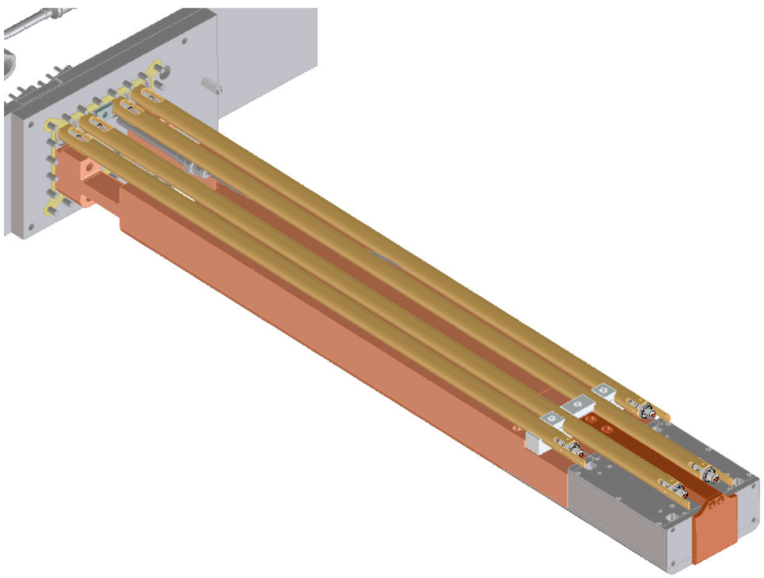
Ionization Chamber Fabrication

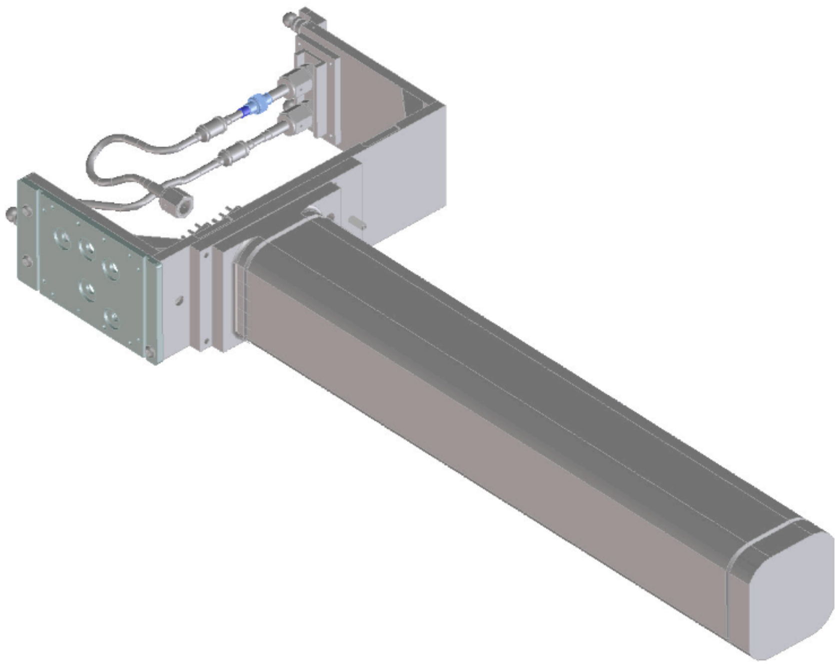
- Electrodes and ground plane
  - OFHC copper
  - Wire Electrical Discharge Machining (Wire-EDM)
  - High precision
  - Ground plane center element is e-beam welded
- Sensor body
  - Macor (Mycalex backup also available)
  - Several fine features with high precision
  - Fasteners for assembly
  - Over-constrained assembly requires some craftsmanship





Detector Assembly





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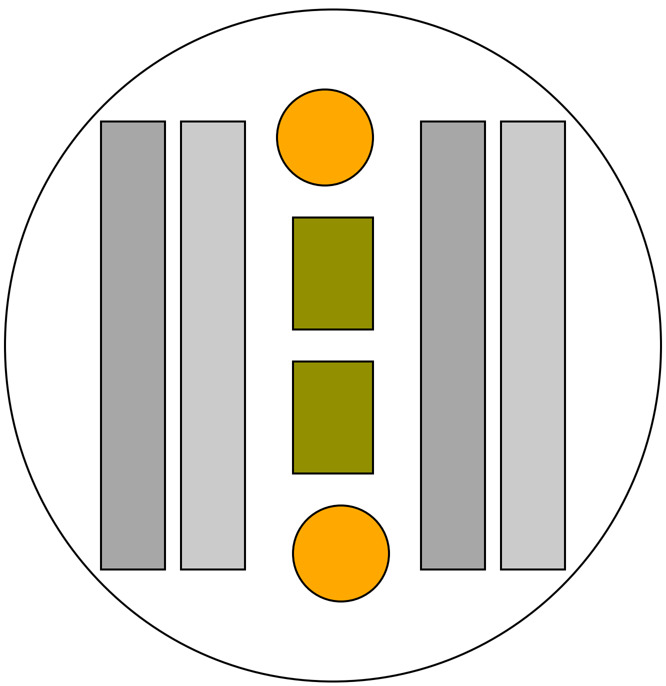
Radiation Hardness Studies at BNL

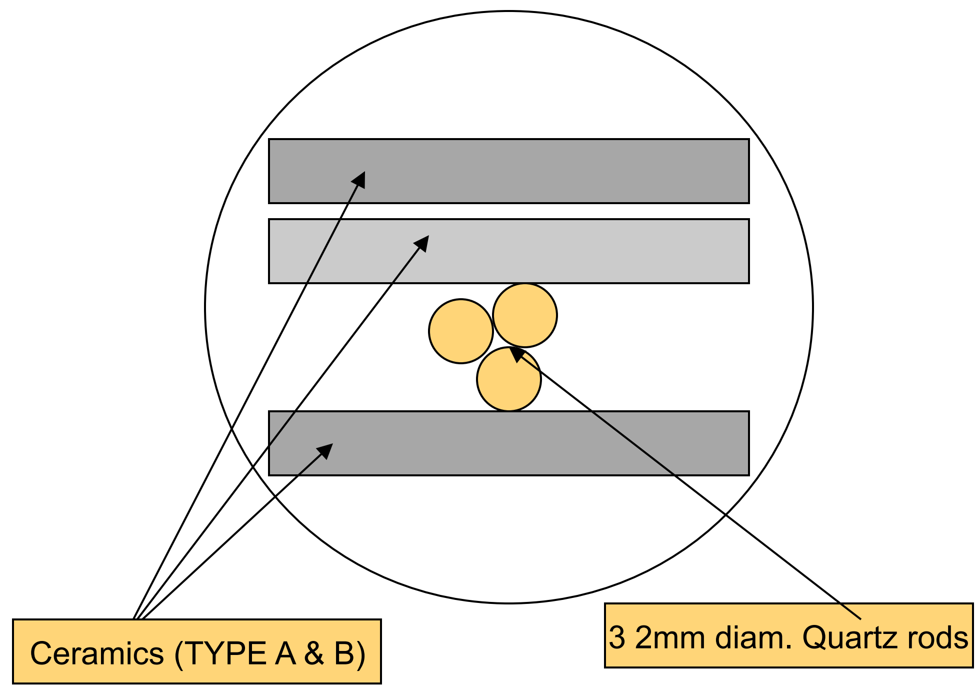
PHASE I: Irradiation with Direct Protons (~ 2 hrs) Leading to GRad-level exposure

PHASE II: Exposure to neutrons (mostly) for several days

200 MeV Proton Irradiation (direct)
Phase I (plus Phase II)



Neutron Exposure
Phase II

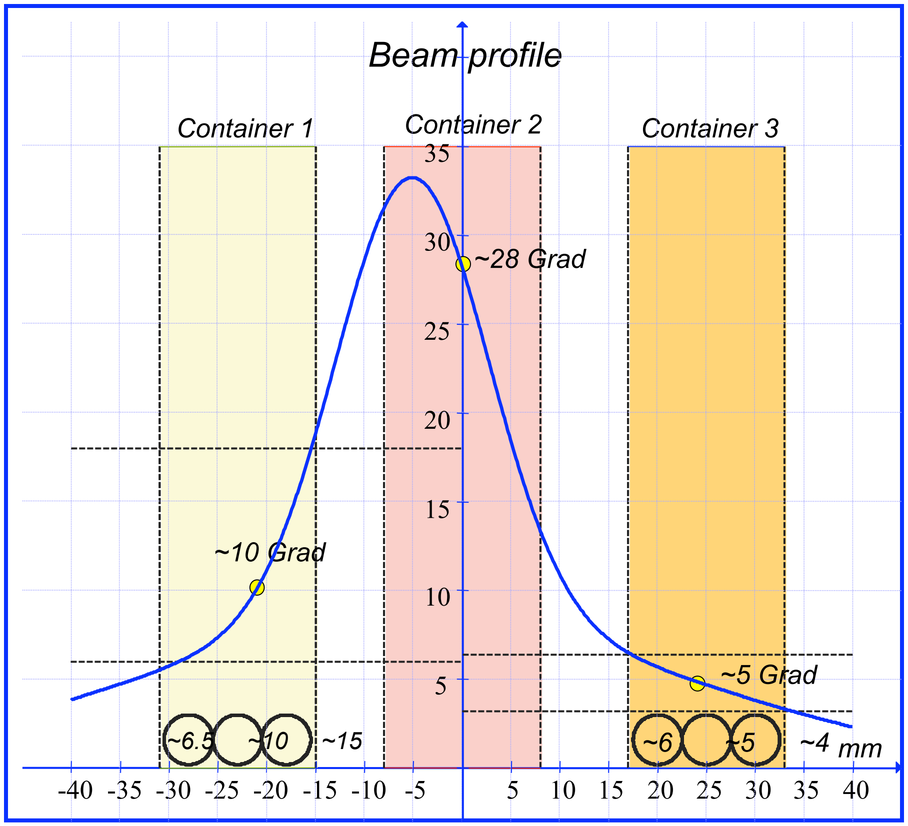


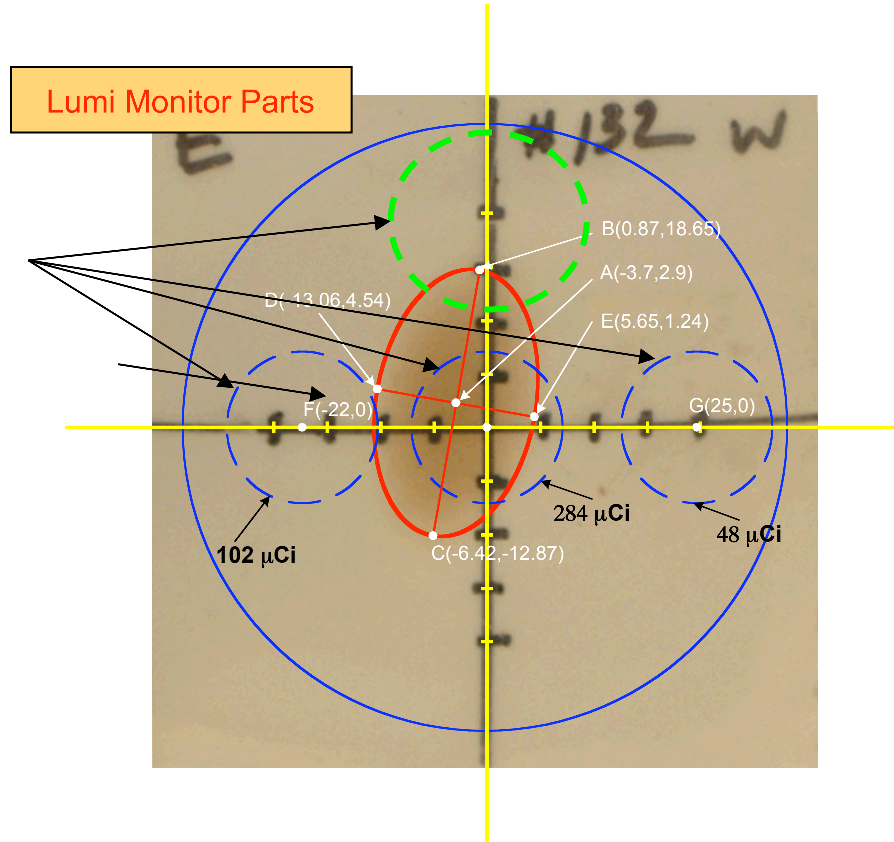
Irradiation Tests

- Proton and/or Neutron GRad-level Irradiation Exposure
  - Ceramics, Resistors and Capacitors
    - Mycalex and Macor
    - Metallized on one side
- 200 MeV and 117 MeV Protons at BNL Isotope Facility
  - Two phases
- Nick Simos (BNL) ran the tests with other LHC components
- Estimated 35 Grad total dose
- No observable problem

Test Condition for Phase I

Spatial Arrangement of
Secondary Containers





Readout System

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Pre-amp board (in tunnel)

- Signal conditioning and amplification for ~300m cable
- Charge sensitive pre-amplifier capable of responding to 25 ns bunch spacing
- S/N ~ 1

Shaper (in the counting room)

- Compensates for effects of detector capacitance as well as long cables
- Signals can be shared with experiments and are available in counting rooms

VME-based DAQ (in the counting room)

- Hardware by CERN
- Core firmware by LARP

Project Recovery

LARP

LARP's Letter of June 2008
- PMTs are welcome and an extremely helpful tool for commissioning LUMI
- LARP plans to have all detectors at CERN in July, install as LHC access permits
  - Some electronics will be completed later in the year
- Install at least one complete system to use with beam in 2008

Two detectors were installed and reading signals with beam in 2008

- A full system will be tested with beam at SPS starting on June 30
  - Validate final design and operation of all components
  - Eric Prebys will attend the tests

Successful test completed

- No doubt all systems will be ready in 2009

All systems are ready for beam

- Looking to allocate more funds to accelerate progress

Some funds were allocated and contributed to keeping the project going

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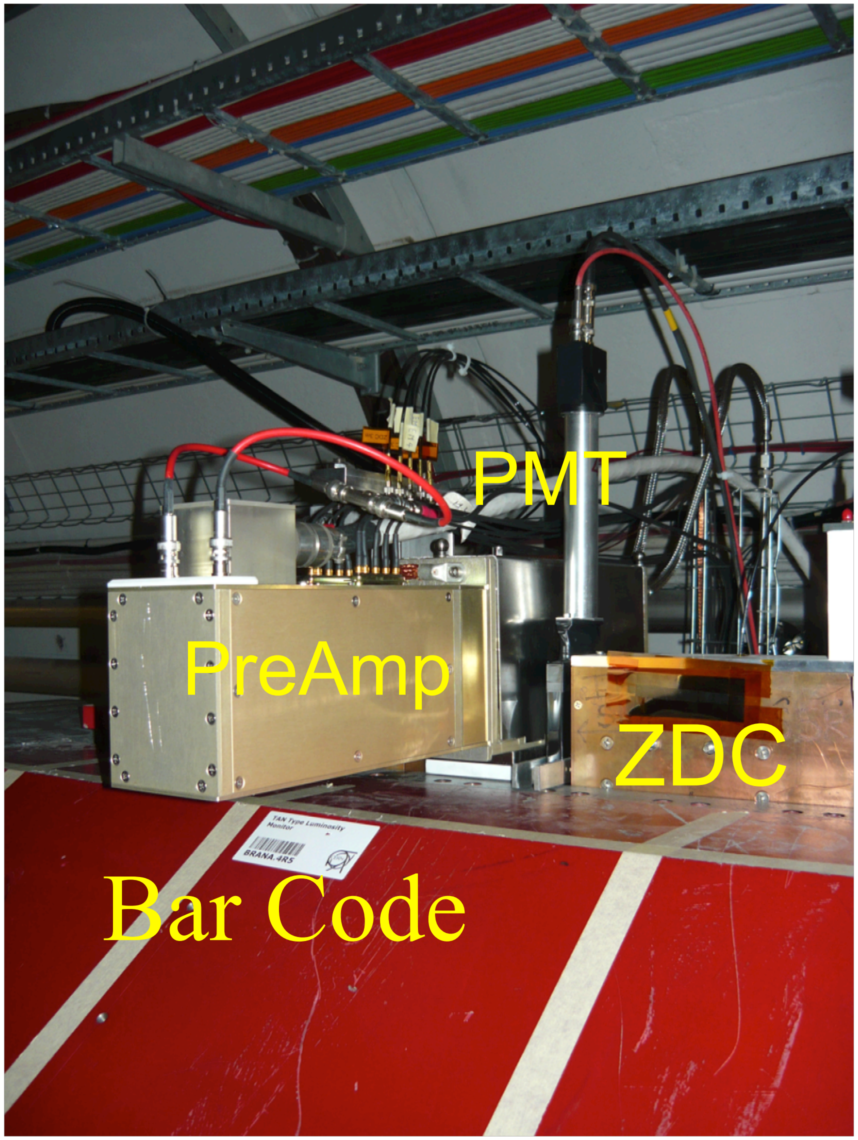
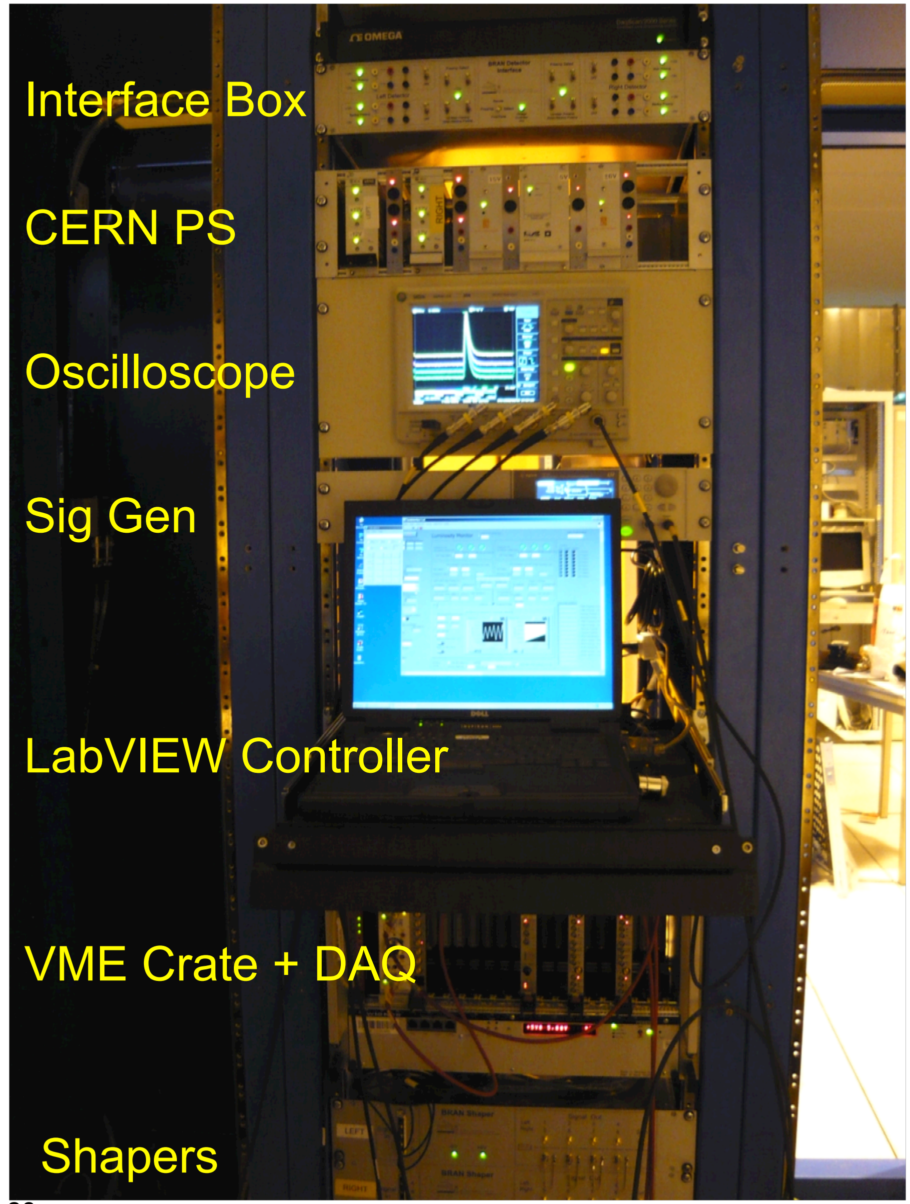
Installation of all 4 units Complete

Tunnel Installations:

- Detectors
- Pre Amps
- Gas connections
- Cabling



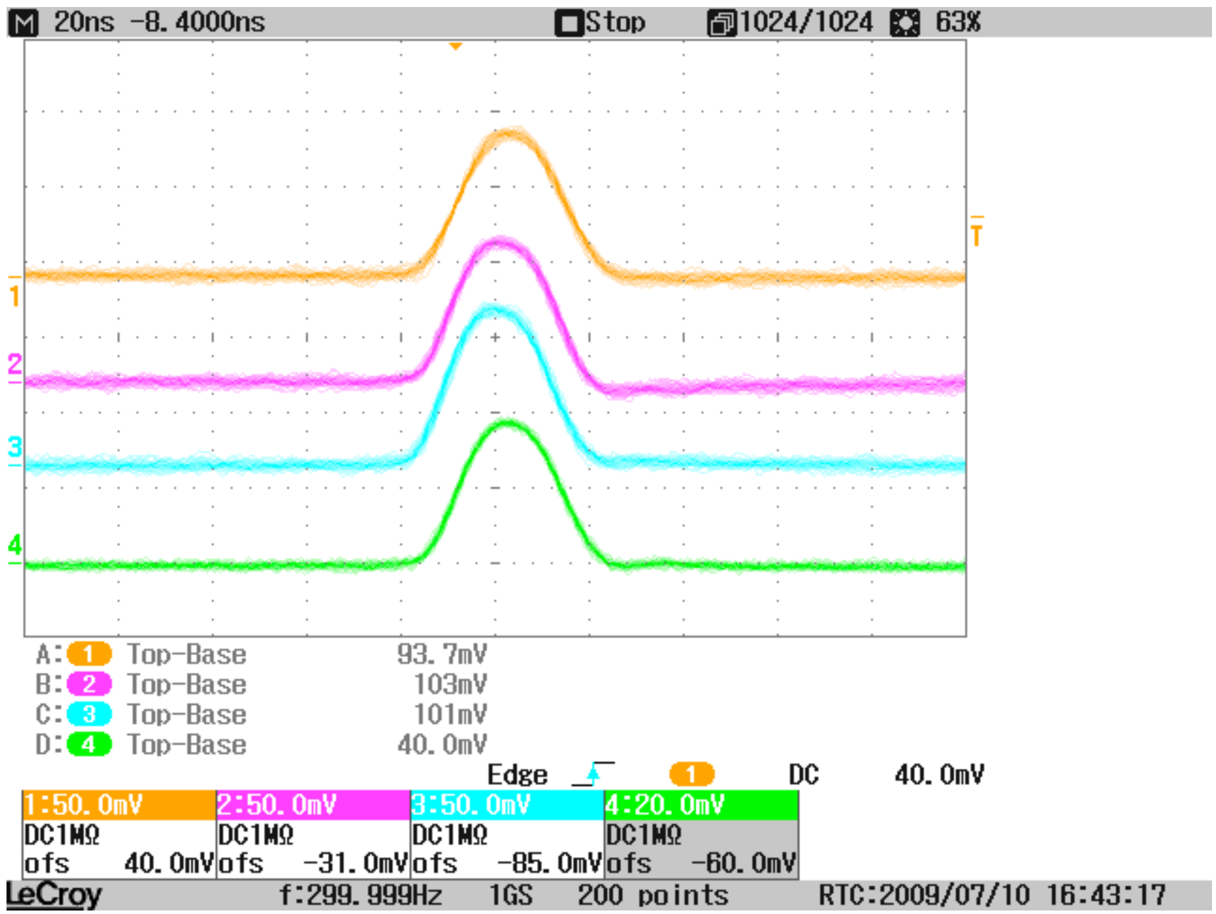
Readout Racks



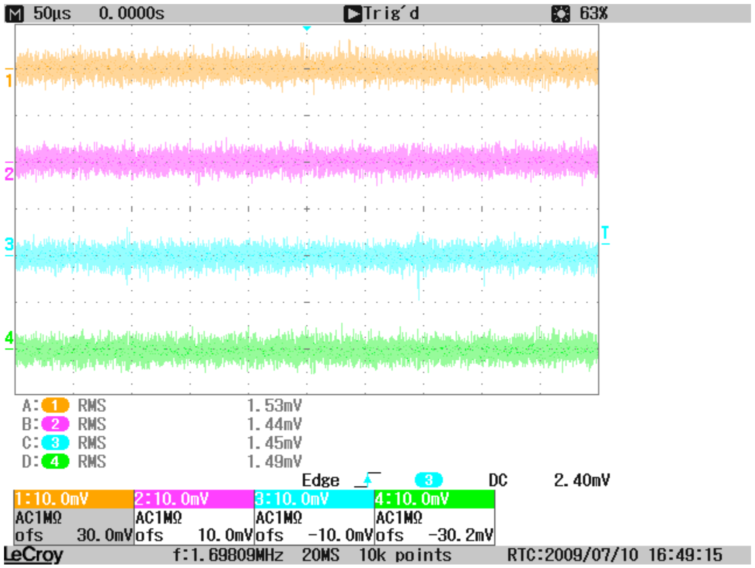
Hardware Commissioning - Analog Electronics

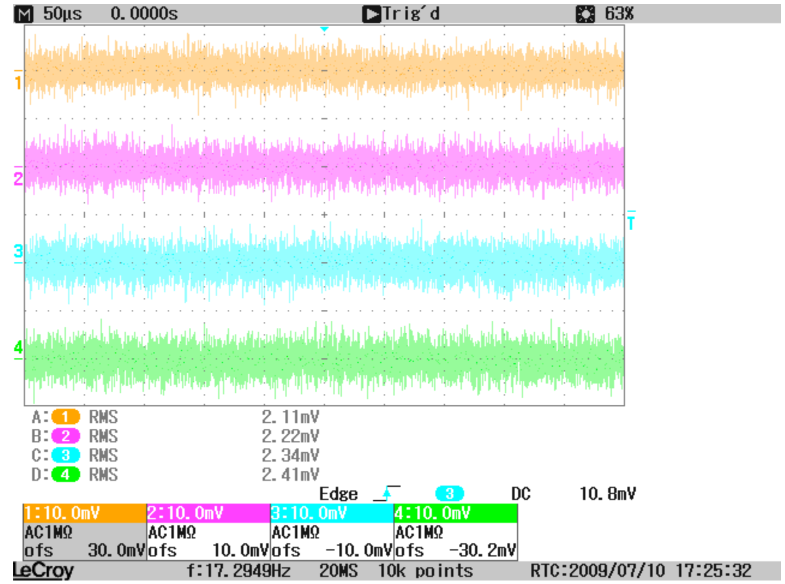
LARP

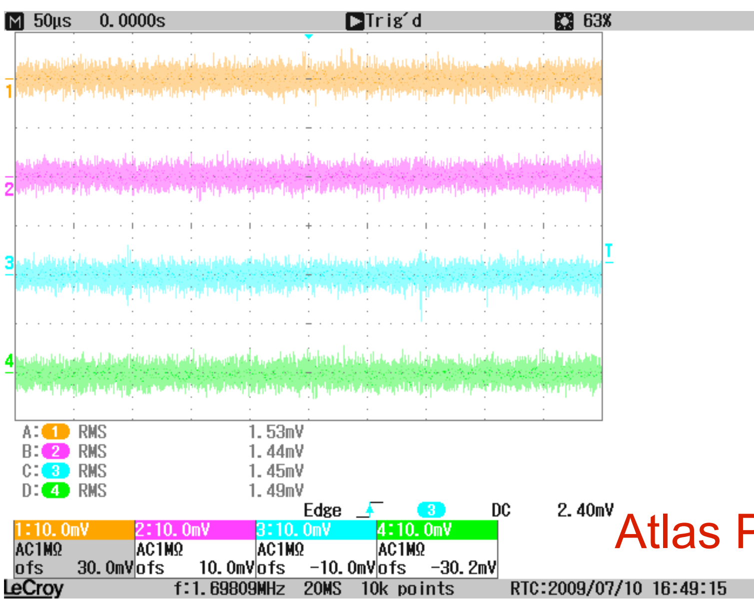
Images of 4 noise baselines at 4 detectors



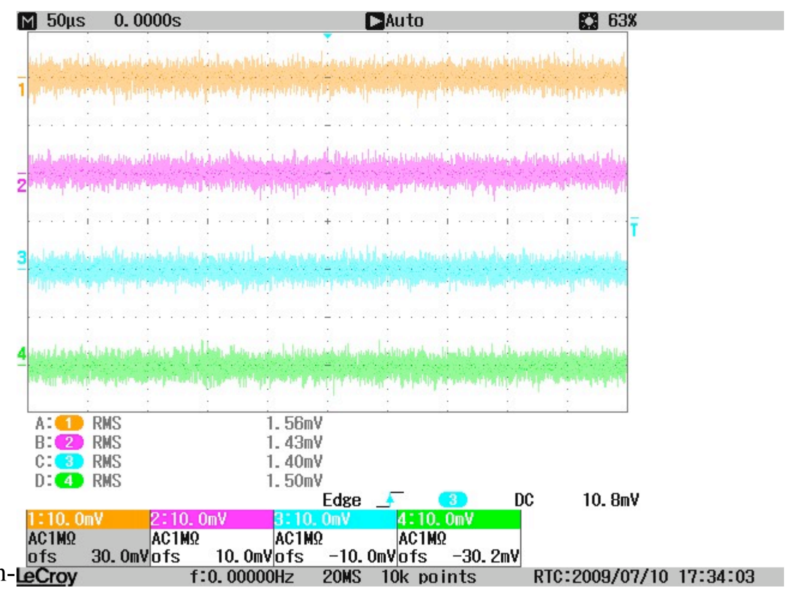
Hardware Commissioning –



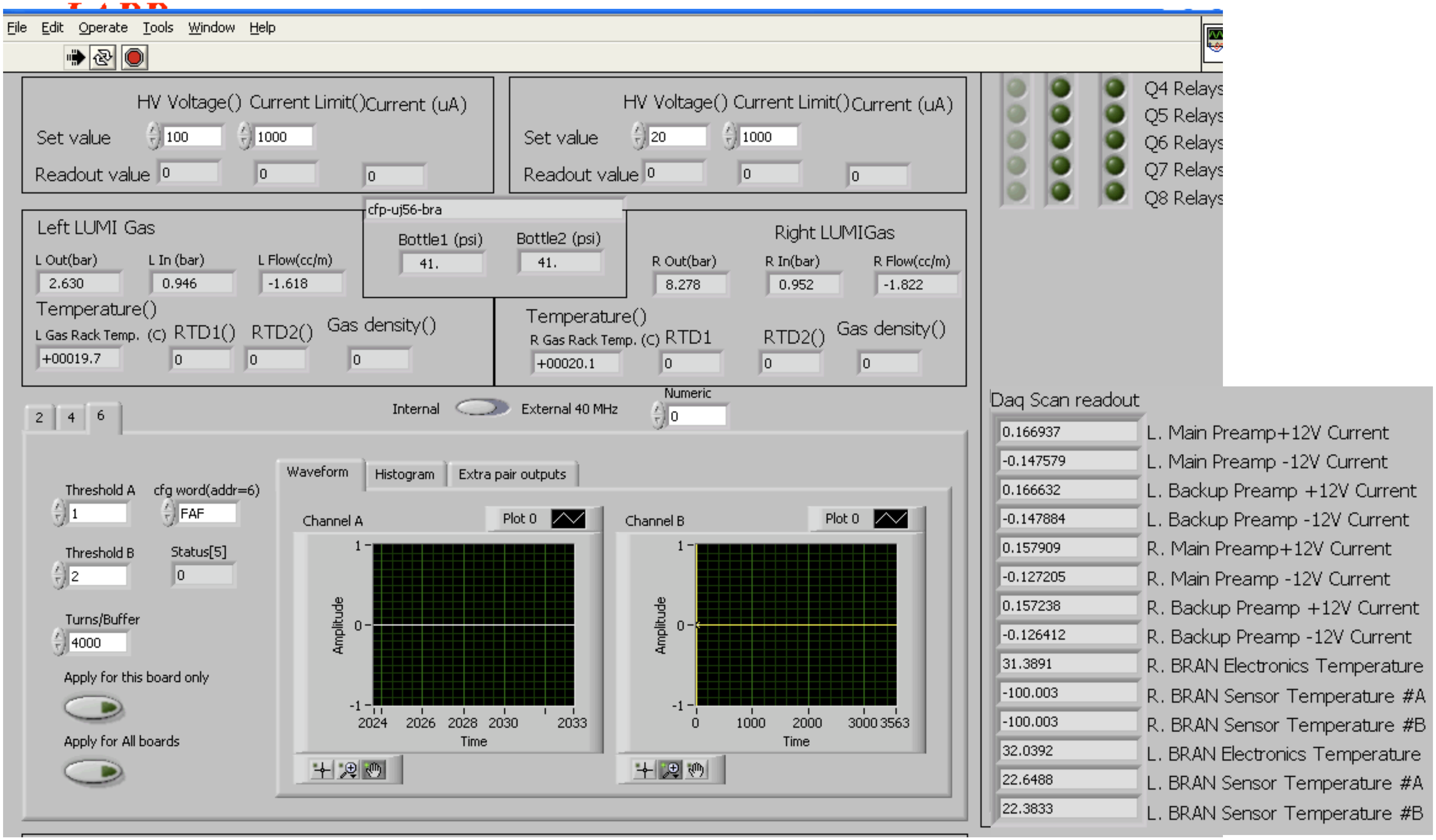




Atlas Pre-Amps



Local Controllers (LabVIEW)



Status Summary

All hardware delivered to CERN

- Installed in final location

All signals checked out

All analog chains adjusted in their final configuration

Documentation of all electronics systems delivered

Mechanical as built drawings in progress

Firmware delivered to CERN

- Integration and handover planned for next two weeks

Handoff to CERN - 1

Transition period – both labs involved in installation and hardware commissioning

LBL
- Deliver all hardware
- Install and test in LHC
- Provide LabVIEW test bench

CERN
- Contribute to installation
- Actively participate in firmware development
- Develop FESA interface

Handoff to CERN - 2

LARP

1. All HW chains simultaneously lab tested for gas, HV, preamp-switching functionality with source-produced pulses processed through shapers into the LabView DAQ

2. All system units (Gas Monitors, Data Interface Boxes) working in racks with control through local PCs and with full functionality

3. Documentation of major components (detectors, preamplifier and shapers) completed, including wiring diagrams

Lumi Project Complete

Handoff to CERN - 3

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CERN takes over responsibility for device operation and maintenance

LARP continues to be involved in beam commissioning and pre-ops

- LTVs, Toohig fellows, collaborations with experiments

LARP Involvement After Project Completion

LBL plans to assist CERN through end of September 2009

- duplicating slow readout/control functionality
- delivering data to end users in control room or other analysis
- verifying that data from first collisions are as expected from test beam & source results

Funds could be available to LBL in FY10 to continue this effort in support of operations

- not guaranteed at the moment

LARP plans to support commissioning and operations through Toohig fellows, LTVs and possible collaborations with ATLAS and CMS

Spares

As part of the project we produced several spares which will be delivered to CERN at project end. This includes:

- one detector
- one shaper
- one preamp
- Various components and spare parts from the fabrication of the devices
- Tooling and fixtures

LHC Beam Commissioning Plans

LARP

Mode	Bunches	Bunch Spacing	Luminosity [cm^{-2} s^{-1}]	Interactions/ Xsing	Mean pulse height/ occupied bunch Xsing - mV
A–Collision studies with single pilot bunch beam - no crossing angle	1	N/A	2.5×10^{26} - 3.7×10^{27}	0.0006-0.092	0.04-0.53
B–Collision studies with single higher intensity bunch - no crossing angle	1	N/A	1.1×10^{29} - 4.3×10^{30}	0.27-10.71	16-611
C–Early p-p luminosity	43	2.025 µs	4.8×10^{30} - 8.4×10^{31}	0.28-4.86	15-277
	2808	25 ns	6.5×10^{32}	0.58	33
	936	75 ns	1.8×10^{33}	4.79	273
D–Nominal p-p luminosity	2808	25 ns	1.0×10^{34}	8.87	506
E–Ultimate p-p luminosity	2808	25 ns	2.3×10^{34}	20.39	1163

Lumi Beam Commissioning Plans

- **A–Collision studies with single pilot bunch beam - no crossing angle**
  - Collision rate too low to use as a luminosity monitor
  - Minimize noise
  - Get baseline software and hardware ready
  - Study beam background (beam-gas, neutron ...)
- **B–Collision studies with single higher intensity bunch - no crossing angle**
  - Start in pulse counting mode
  - Transition to pulse height mode
  - Plan for crossing angle algorithms
  - Need sustained presence at CERN
- **C–Early p-p luminosity**
  - Develop deconvolution algorithms
  - May need deconvolution for this phase
  - Implement and test crossing angle algorithms
  - Can do pulse counting for most of this period
  - Develop pulse height mode algorithms
- **D–Nominal p-p luminosity**
  - Pulse height mode
  - Deconvolute
  - Detector needs to fully commissioned with gas flow
- **E–Ultimate p-p luminosity**
  - Might need to lower pressure to reduce voltage

LLRF Modeling

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Leveraging the experience with PEP-II the group is actively working to help model the LHC RF system and its components

The goal is to adapt and expand the existing models to a hadron collider and storage ring

Supported beam commissioning by provided highly experienced engineers during the tuning and hardware calibrations before the 2008 run

Measured transfer functions, open and closed loop

Studying noise budget by modeling key components to qualify the impact of noise on emittance growth (expected large)

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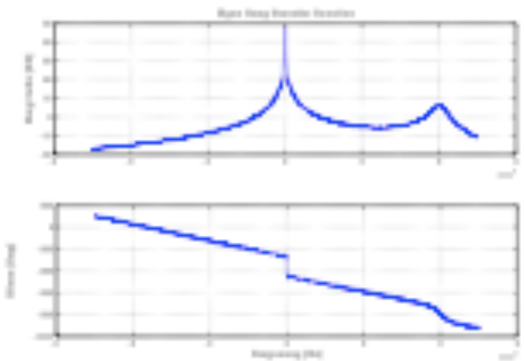
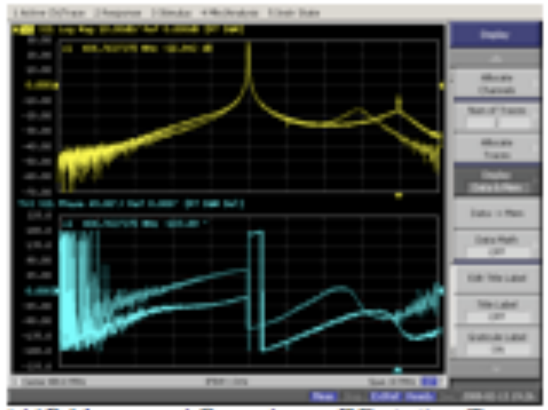
Transfer Function Measurements

Open Loop RF Station Transfer Functions

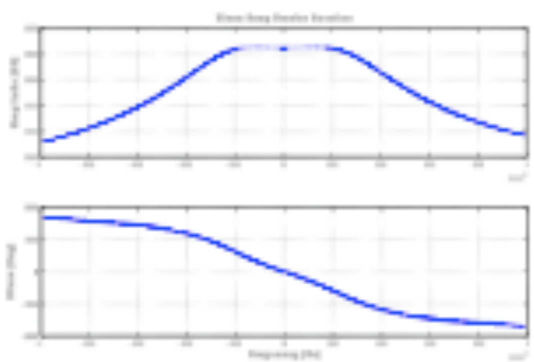


SLAC Simulated Open Loop RF station Transfer Function

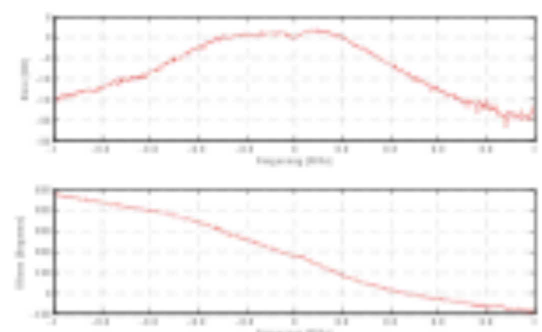


LHC Measured Open Loop RF station Transfer Function (two different RF stations)

Closed Loop RF station Transfer Functions



SLAC Simulated RF station Closed Loop Transfer Function



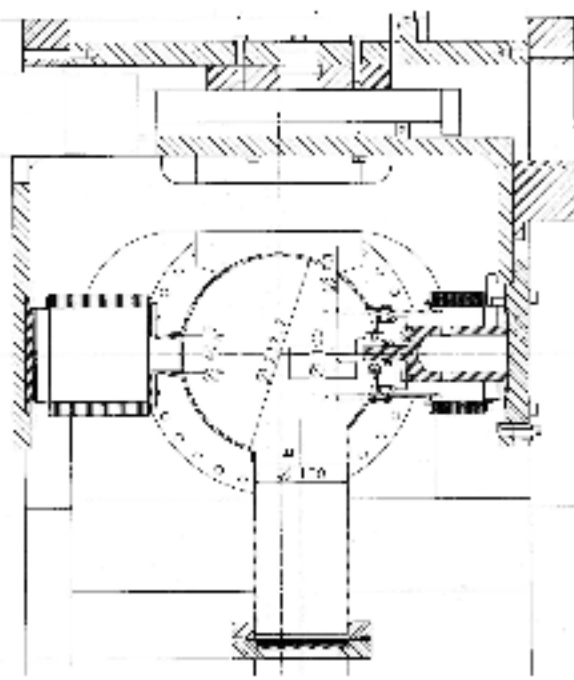
LHC Measured RF station Closed Loop Transfer Function

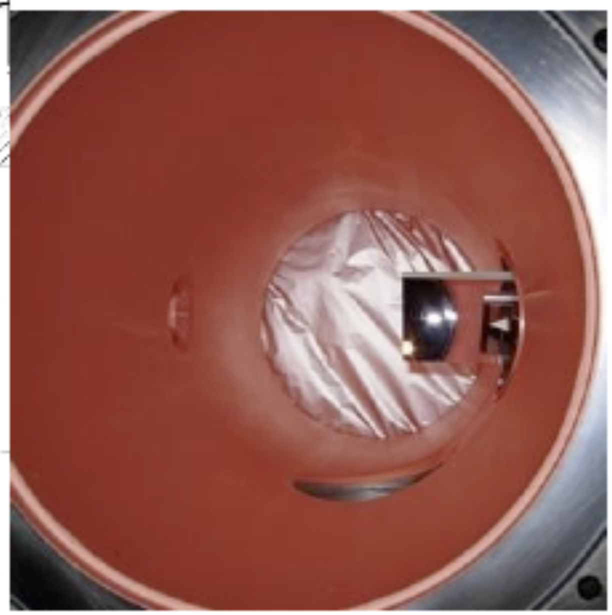
Synch Light Monitors – Abort Gap

Alan Fisher- LTV from SLAC

Monitor radiation emitted by dipole bend magnets
and short undulator at low energy (< 2TeV)

Extracted by mirror and transported/focussed by a dedicated system
Image with cameras





Measure
- beam profile and
- beam in abort gap

Protons and Heavy Ions

LARP

Heavy Ions Synchrotron Radiation

- ALICE will study collisions of lead ions.
- Planned for ~3 weeks in 2010, at the end of the run.
- Ion energy determined by maximum dipole field:
  - Inject at 36.9 TeV/ion, or 177 GeV/nucleon
  - Collide at 574 TeV/ion, or 2.76 TeV/nucleon
    - 82 times the kinetic energy of a mosquito at 1 m/s
    - Kinetic energy of a 1-mm-diameter grain of sand at 40 km/h
- Fewer bunches and fewer particles/bunch:
  - Ions: 592 bunches of $8.2\times10^{9} = 4.9\times10^{12}$
  - Protons: 2808 bunches of $1.2\times10^{11} = 3.4\times10^{14}$
  - Similar quench limit

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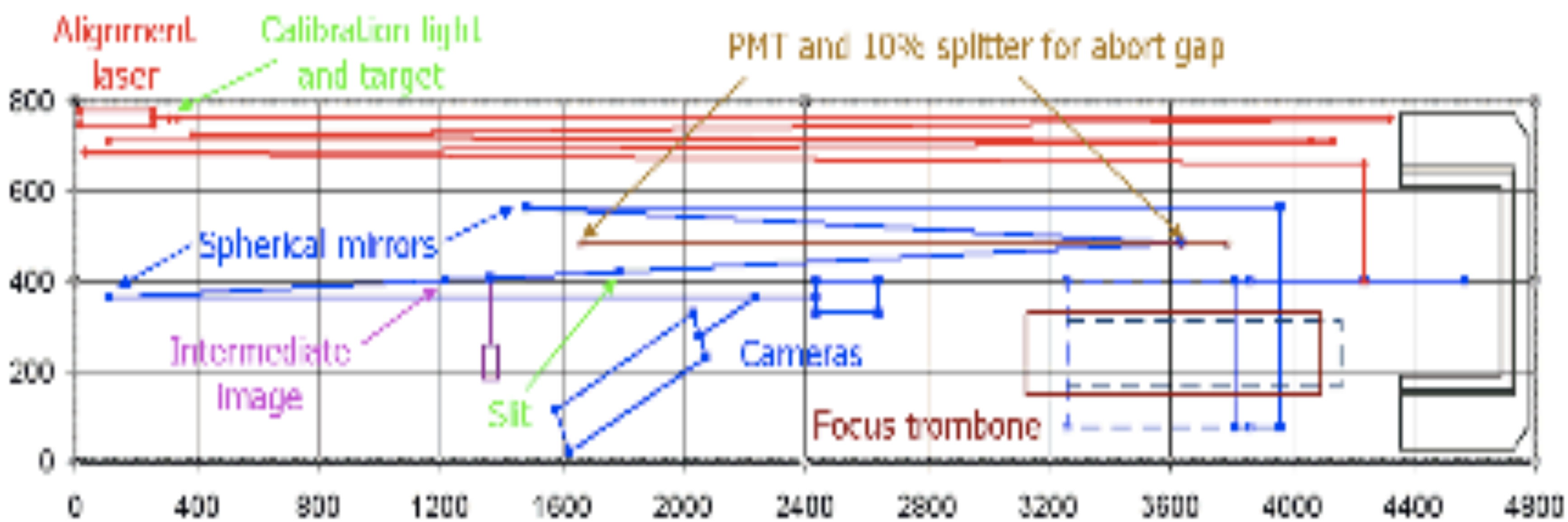
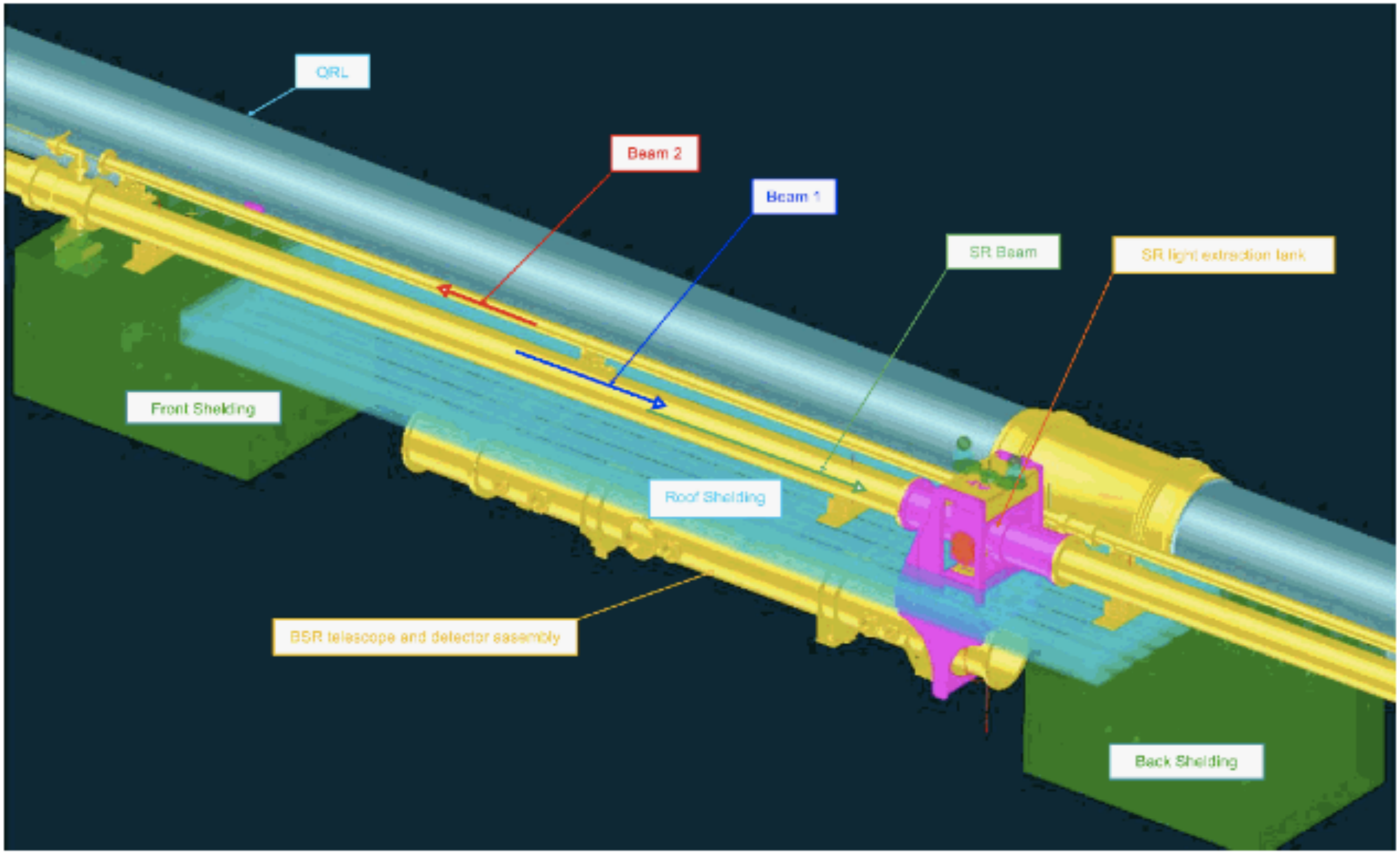
Optics Layout



Synch


QRL
Beam 2
Beam 1
SR Beam
SR light extraction tank
Front Shelding
Roof Shelding
BSR telescope and detector assembly
Back Shelding

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Final Considerations

Results made possible by significant contributions from all labs

- Lumi monitor initially funded by LBL for 3 years
- AC dipole enhanced by BNL and FNAL
- Schottky monitor controls interfaces contributed by FNAL
- Synch Light Monitor (LTV) and LLRF – SLAC

Working with LARP management to secure adequate resources in support of the LHC commissioning

LTVs and Toohig fellows

Integration with beam commissioning activities is essential to the success of the instruments provided by the LARP collaboration

Final Considerations – 2

Students are an essential part of instrumentation

- AC dipole – PhD thesis
- Lumi – Master student won award from CA APS
- LLRF – PhD thesis
- Toohig fellow to follow lumi at CERN

Very innovative projects

- AC dipole concept incubated by LARP
- Lumi aims at 100x radiation levels ever seen
- Looking at synch light from heavy ions
- Tune and coupling feedback a world first

LARP

Summary

Spending roughly 10% of LARP's budget to date, the instrumentation program has delivered direct contributions that will help the LHC commissioning and performance improvements from day one.

Made possible by collaborations with CERN and contributions of each of the LARP labs

Adding significant, tangible contributions every year
- Synch light abort gap monitor

New proposals keep coming but face reducing budgets and other priorities

This program will advance the US HEP program by
- Enhancing US accelerator skills
- Developing advanced diagnostic techniques that will apply to present and future US programs
- Help maximize LHC performance